Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project

SIO Kick-Off Meeting

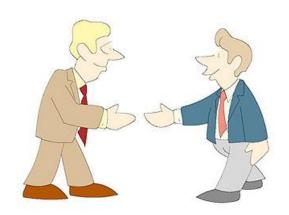October, 2018

UAS INTEGRATION IN THE NAS

Overview

- Welcome and Introduction
- SIO Scope and Objectives
- Schedule
- Partnership Requirements Overview
- NASA UAS-NAS Project Experience
  - Detect and Avoid
  - Command and Control
  - No Chase COA
  - Certification
- Working Group Structure and Communications
- Public Relations
- NASA Resources
- Data Management Plan and Intellectual Property Protection
- FAA Participation
- Airworthiness and Operational Approval

Welcome to the SIO Kickoff Meeting!

- Team introduction
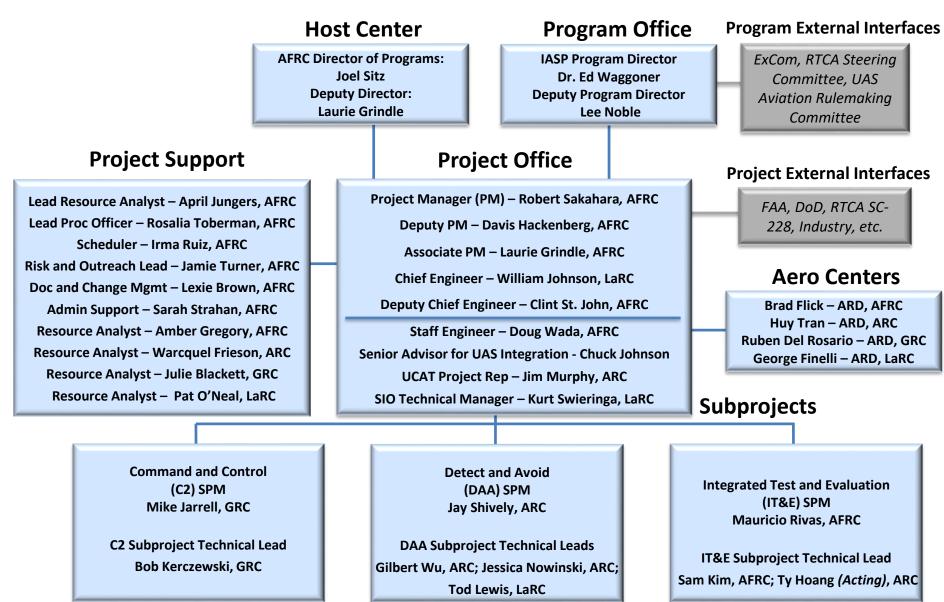- Handout with description of NASA team members
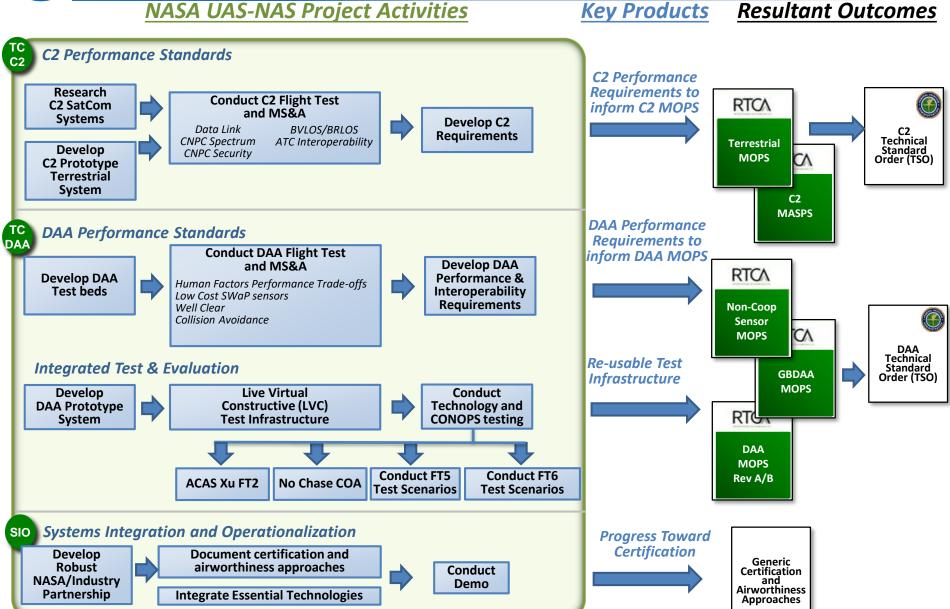
SIO SCOPE AND OBJECTIVES

NASA Organizational Structure

Mission Directorates

Aeronautics Research Centers

UAS Integration in the NAS Organizational Structure

Host Center

AFRC Director of Programs:
Joel Sitz
Deputy Director:
Laurie Grindle

Program Office

IASP Program Director
Dr. Ed Waggoner
Deputy Program Director
Lee Noble

Program External Interfaces

ExCom, RTCA Steering Committee, UAS Aviation Rulemaking Committee

Project Support

Lead Resource Analyst – April Jungers, AFRC
Lead Proc Officer – Rosalia Toberman, AFRC
Scheduler – Irma Ruiz, AFRC
Risk and Outreach Lead – Jamie Turner, AFRC
Doc and Change Mgmt – Lexie Brown, AFRC
Admin Support – Sarah Strahan, AFRC
Resource Analyst – Amber Gregory, AFRC
Resource Analyst – Warcquel Frieson, ARC
Resource Analyst – Julie Blackett, GRC
Resource Analyst – Pat O'Neal, LaRC

Project Office

Project Manager (PM) – Robert Sakahara, AFRC
Deputy PM – Davis Hackenberg, AFRC
Associate PM – Laurie Grindle, AFRC
Chief Engineer – William Johnson, LaRC
Deputy Chief Engineer – Clint St. John, AFRC

Staff Engineer – Doug Wada, AFRC
Senior Advisor for UAS Integration - Chuck Johnson
UCAT Project Rep – Jim Murphy, ARC
SIO Technical Manager – Kurt Swieringa, LaRC

Project External Interfaces

FAA, DoD, RTCA SC-228, Industry, etc.

Aero Centers

Brad Flick – ARD, AFRC
Huy Tran – ARD, ARC
Ruben Del Rosario – ARD, GRC
George Finelli – ARD, LaRC

Subprojects

Command and Control
(C2) SPM
Mike Jarrell, GRC

C2 Subproject Technical Lead
Bob Kerczewski, GRC

Detect and Avoid
(DAA) SPM
Jay Shively, ARC

DAA Subproject Technical Leads
Gilbert Wu, ARC; Jessica Nowinski, ARC;
Tod Lewis, LaRC

Integrated Test and Evaluation
(IT&E) SPM
Mauricio Rivas, AFRC

IT&E Subproject Technical Lead
Sam Kim, AFRC; Ty Hoang *(Acting)*, ARC

ARD: Aeronautics Research Director, PM: Project Manager, SPM: Subproject Manager, UCAT: Urban Air Mobility Coordination Assessment Team, SIO: Systems Integration and Operationalization

UAS-NAS Project Value Proposition

NASA UAS-NAS Project Activities

TC C2 — C2 Performance Standards

- Research C2 SatCom Systems
- Develop C2 Prototype Terrestrial System

→ Conduct C2 Flight Test and MS&A

- Data Link
- CNPC Spectrum
- CNPC Security
- BVLOS/BRLOS
- ATC Interoperability

→ Develop C2 Requirements

TC DAA — DAA Performance Standards

- Develop DAA Test beds

→ Conduct DAA Flight Test and MS&A

- Human Factors Performance Trade-offs
- Low Cost SWaP sensors
- Well Clear
- Collision Avoidance

→ Develop DAA Performance & Interoperability Requirements

Integrated Test & Evaluation

- Develop DAA Prototype System

→ Live Virtual Constructive (LVC) Test Infrastructure

→ Conduct Technology and CONOPS testing

- ACAS Xu FT2
- No Chase COA
- Conduct FT5 Test Scenarios
- Conduct FT6 Test Scenarios

SIO — Systems Integration and Operationalization

- Develop Robust NASA/Industry Partnership

→ Document certification and airworthiness approaches

→ Integrate Essential Technologies

→ Conduct Demo

Key Products | Resultant Outcomes

C2 Performance Requirements to inform C2 MOPS
→ RTCA: Terrestrial MOPS, C2 MASPS → C2 Technical Standard Order (TSO)

DAA Performance Requirements to inform DAA MOPS
→ RTCA: Non-Coop Sensor MOPS, GBDAA MOPS

Re-usable Test Infrastructure
→ RTCA: DAA MOPS Rev A/B → DAA Technical Standard Order (TSO)

Progress Toward Certification
→ Generic Certification and Airworthiness Approaches

Systems Integration and Operationalization (SIO)

- SIO stands for **Systems Integration and Operationalization**
  - **Systems Integration:** Includes integration of all UAS systems required for a mission
  - **Operationalization:** Make progress toward enabling UAS operations in the NAS

- Philosophy behind SIO
  - Industry is making significant investments in UAS development
  - Industry would like to commercialize their UAS and UAS technologies
  - NASA has expertise in critical UAS systems, airworthiness, and certification
  - The FAA is willing to work with industry to certify UAS that do not fall under Part 107

Goal: Leverage the expertise of industry, NASA, and the FAA to make progress toward commercial UAS operations in the National Airspace System

Maximum contribution from NASA

NASA
- Command and Control (C2) and Detect and Avoid (DAA)
- UAS Airworthiness
- Subject matter expertise
- Type certification lessons learned

UAS-NAS RTT (SC-228)

DAA/C2, Airworthiness Criteria

SIO

FAA role

Minimum contribution from Industry

FAA
- Approval to fly in the NAS
- Type Certification guidance
- Procedural, policy, and regulatory changes

Certification, Operational Approval

Industry
- Airworthy vehicle with integrated C2 and DAA equipage
- Other gap filling technologies required for missions
- Specific Type Cert Basis

Systems Integration and Operationalization (SIO) Partnership

UAS-NAS Project – SIO Operational View Representation

National Aeronautics and Space Administration

Communications Satellite

HALE Airspace Integration

SatCom BVLOS Communications

IFR-Like Airspace Integration

Cooperative Aircraft

ADS–B & TCAS–II / ACAS Xu

Airborne Detect and Avoid

DAA Sensors

UAS test aircraft

Non-cooperative Aircraft

SatCom Transmitter

Land Line

UAS Ground Control Station

Terrestrial C2

CNPC Ground Stations

Terrestrial C2 Link

Land Line

UAS Ground Control Station

Terminal Airspace Airspace Integration

ATC Interoperability

Ground Based Detect & Avoid

Non-cooperative Aircraft

Alternative DAA Sensors

"mid-sized" test aircraft

Ground Based Radar

VFR-Like Airspace Integration

LEGEND
- Detect and Avoid (DAA) Technologies
- Air Traffic Control (ATC) Services
- Control and Non-Payload Communications (CNPC) Network
- Satellite Command and Control (C2) Links

ACRONYMS
ACAS Xu: Airborne Collision Avoidance System, UAS Variant
ADS–B: Automatic Dependent Surveillance—Broadcast
BRLOS: Beyond Radio Line of Site
BVLOS: Beyond Visual Line of Site
TCAS–II: Traffic Alert and Collision Avoidance System
UAS: Unmanned Aircraft Systems

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SIO Overview

NASA provides a foundation of expertise from years of research, which will be used to help industry partners obtain operational approval

Industry provides vehicle development, integration, operations, and lead FAA Type Certification effort

Flight Demonstration in FY2020

Progress toward UAS Type Certification

Documentation of Type Certification lessons learned

SIO Overview
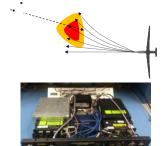
Flight Demonstration
in FY2020

Seek approval
to fly in the NAS

Demonstration emulating
commercial ConOps

Integrated DAA and
C2 systems

Progress toward UAS
Type Certification

- Industry partners expected to lead Type Certification effort
- Leverage relationships with the industry partners and the FAA
- Full certification is not expected by 2020, but progress is

Documentation of Type
Certification lessons learned

- Description of Concept of Operations (ConOps) for SIO missions
- Risk-based safety assessment of SIO missions
- Lessons learned from SIO Type Certification efforts
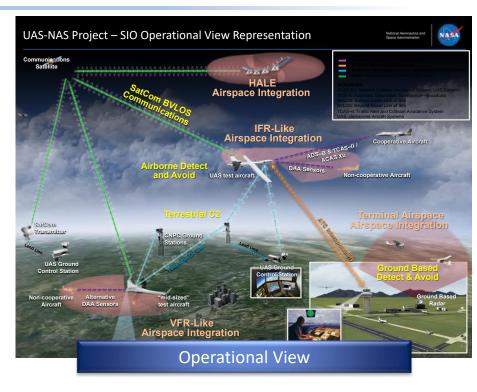
SIO High Level Summary

Goal: Work toward routine commercial UAS operations in the National Airspace System (NAS)

- Obtain approval to operate in the NAS for a FY2020 flight demonstration
- Demonstrate integrated Detect and Avoid (DAA) and Command and Control (C2) technologies
- Work toward Type Certification

Operational View

SIO Partnership

Method: Partnership with industry

- Industry provides UAS development, integration, testing, operations, and begin type certification process
- NASA provides subject matter expertise in DAA, C2, airworthiness, and certification
- NASA will keep the FAA informed of Type Certification efforts via the Research Transition Team (RTT)

SCHEDULE

Milestone Schedule

Milestones	Date
Kick-off Meeting	October 2018
Baseline Mission ConOps Document	March 2019
Baseline Risk-based Safety Assessment Document	June 2019
System Test/Acceptance Plan Complete	October 2019
Project Specific Certification Plan Complete	December 2019
UAS Operating Manual	January 2020
Acceptance Test Report Complete	May 2020
All airworthiness artifacts provided	May 2020
System Design Document Complete	May 2020
Flight Demonstration Plan	May 2020
FY2020 Flight Demonstration of Commercial ConOps Complete	July 2020
Final Report	August 2020

Note: the SIO activity must be complete by September 30, 2020, which is the date when the UAS-NAS project ends

Important Schedule Constraint

SIO must be complete by the end of FY2020 (September 30, 2020)

- The UAS-NAS Project ends on September 30, 2020 and neither monitory support nor personnel support will be available from NASA after that date
  - The FY2020 flight demonstration must be completed prior to September 30, 2020
  - Earlier completion is highly desired to ensure time for project closeout

- Best practices to ensure successful completion and minimize risk:
  - Early identification and communication of schedule risks
  - Open and frequent communication
  - If needed, joint evaluation of options to meet SIO objectives by the end of FY2020

PARTNERSHIP REQUIREMENTS OVERVIEW

Documentation

- The documentation requested as part of the Cooperative Agreement is intended to be useful
  - Facilitate information exchange between NASA and Partners
  - Develop artifacts needed for certification and demonstration approvals
  - Facilitate communication of project status, risks, and action items

- The format of the documentation is flexible and can be aligned to match company and/or industry standard formats
  - Either PowerPoint presentations or documents may work as long as they meet the objectives
  - Exception is any documentation required to satisfy NASA's airworthiness process, which has a defined format (NASA personnel will assist)

- Documentation that currently exists should be shared as soon as possible
  - Sharing documentation/information as soon as it is available will improve NASA ability to provide recommendations and contributions

- The documentation should include clear marking of proprietary information
  - NASA is requesting two versions of each document:
    - Unrestricted
    - Complete version with appropriate restrictions
  - This is a communication method to make sure that the delineation between publicly available information and proprietary information is clear

Please do not provide any classified information to NASA during this activity

Documentation Objectives

#	Document	Date (No Later than)	Objective/Use
1	Kick-off Meeting	October 2018	Ensure clear communication of project scope, objectives, and how NASA and the Partner will work together
2	Monthly Status Reports	End of each month	Facilitate communication of project status, risks, and action items
3	Mission ConOps	March 2019	A description of the Concept of Operations, which is expected to be relevant to the type certification and the process of obtaining approval to operate in the National Airspace System (NAS) for the SIO flight demonstration.
4	Risk-based Safety Assessment	June 2019	The risks, hazards, and mitigations that will form the safety case required to obtain airworthiness approval, approval to operate in the NAS, and the safety case required for type certification. While there may be differences between the safety case for the SIO demonstration and type certification, there are also expected to be a lot of commonality. NASA will also leverage the safety case when creating publicly available certification documentation.
5	Flight Demonstration Plan and Supporting documentation for airworthiness approval	May 2020	The *Flight Demonstration Plan* will be used to communicate details of the flight demonstration to NASA and the FAA to facilitate the process of obtaining approval to operate in the NAS.
6	UAS Operating Manual	January 2020	Portions of the safety case will depend on how remote pilots are trained and how the the unmanned aircraft is operated. NASA would like to understand how the unmanned aircraft is operated in order to provide improved recommendations on the safety case. This objective may be met with existing training and operations documentation.

Documentation Objectives

#	Document	Date (No Later than)	Objective/Use
7	Project Specific Certification Plan	December 2019	Kick off the type certification process and ensure a common understanding of the certification plan.
8	Certification Artifacts	When baseline versions are complete	Sharing certification artifacts will facilitate NASA involvement. NASA will also leverage the certification artifacts when creating publicly available certification documentation.
9	System Design Document	May 2020	The *System Design Document* will be used by NASA to understand the system design of the UAS and applicable systems and subsystems. The design of the UAS may impact the safety assessment and type Certification process. Note that comprehensive PDR/CDR documentation will likely fulfill this requirement.
10	Test/Acceptance Plan	October 2019	Obtaining airworthiness approval and means of compliance for type certification will require planned tests with acceptance criteria. The Test/Acceptance Plan will be used to document those tests and provide input on test procedures (particularly related to DAA and C2 systems).
11	Final Report	August 2020	Part of NASA's mission is to disseminate information to the public. This report will be a summary of the SIO activity with contributions from the industry partners. The expectation is that the Final Report will be a conference paper (~10 to 15 pages) with 3 to 4 pages of material from each industry partner.
12	Graphics and photographs for use in publications and media	As completed	The photographs and graphics will be used in publicly available publications, technical briefings, and media articles/materials. It is expected that either existing graphics and photographs will fulfill this objective.

Documentation Archive Plan

- All unrestricted documents will be retained in a project archive and on NASA computers

- Unrestricted documents, or portions unrestricted documents, may be publicly released
  - NASA will work with Partners to identify information that is appropriate for public release

- Proprietary documents will be removed from NASA computers within a reasonable period of time after project completion unless NASA regulations/policy require them to be kept
  - Any documents required for NASA airworthiness approval will be retained by the Armstrong Chief Engineer's office
  - Current processes will be used to protect restricted information

PARTNERSHIP RESPONSIBILITIES

Subset of NASA and Partner Responsibilities

NASA Responsibilities

- Providing subject matter expertise and recommendations

- Providing access to releasable previous research and planned future research

- Coordination with the FAA via the RTT meeting

- Providing input into trade analyses

- Pointing out items that do not appear to be MOP compliant and advise on relevant test cases

Working Groups

Public Relations

Reports

Presentations

Partner Responsibilities

- Software and hardware development

- Verification and Validation of software and hardware

- Conducing flight demonstration

- Leading the type certification effort

- Leading trade studies

- Ensure MOPS compliance (if applicable)

NASA and Partner Responsibilities

- In general, NASA's role will be advisory in nature, but there are exceptions:
  - The partner must follow NASA airworthiness requirements
  - NASA can call a halt to SIO demonstration flight activities due to significant safety concerns
  - NASA can call a halt to SIO demonstration due to failure to follow FAA or other government regulations (not expected to occur)

- Implications (with exceptions noted above)
  - NASA will not dictate a particular design
    - The UAS is your commercial product
  - NASA will not assume responsibly for confirming that DAA and C2 systems conforms to Minimum Operational Performance Standards
    - NASA will look at prototypes and documentation to help identify areas where those systems do not conform
  - NASA will not verify/validate software and hardware
    - NASA may recommend particular tests
  - NASA cannot confirm that a safety case for a COA or certification is adequate
    - That is the FAA's role
    - NASA can work with you to help facilitate strong COA/certification applications

General Partnership Requirements

NASA Responsibilities

- Attend technical reviews (either in person or virtually)
- Provide research results
- Allow industry partners to review NASA produced publications (Conference/technical papers, technical presentations, etc.)
- Coordinate with the FAA via the Research Transition Team (RTT)
- Provide consultation on the partner's DAA and C2 systems, and certification efforts
- Schedule and host a semi-annual project review
- Lead regular Working Group meetings
- Work with the industry partners on any public relations and media outreach
- If requested and if resources allow, support creation of new LVC connections

Partner Responsibilities

- Provide unmanned aircraft and associated systems
- Conduct appropriate design reviews
- Responsible for any system development, integration, and verification and validation required
- Responsible for collecting artifacts necessary to obtain airworthiness approval for the SIO demonstration
- Responsible for making progress toward type certification
- Review technical reports and conference papers produced by NASA within 20 days
- Support regular Working Group meetings
- Support kick-off meeting and provide monthly status reports
- Support SIO demonstration planning
- Work with the NASA on any public relations and media outreach
- Get permission before using NASA's logo
- If connecting to NASA assets or networks, follow NASA regulations
- Provide access and content to media and the public during the demonstration
- Work toward commercial operations
- No use of any DJI equipment due to cyber security concerns

NASA Responsibilities

- Review the *Mission ConOps* document and provide comments and recommendations
- Work with partners to make sure RTCA SC-228 is aware of relevant portions of the ConOps
- Ensure that the FAA is aware of the ConOps via the Research Transition Team

Partner Responsibilities

- Develop and provide a *Mission ConOps* document
- Coordinate with RTCA SC-228 to present any relevant DAA and C2 aspects of the ConOps (not a requirement, but highly recommended)

Safety and Certification

NASA Responsibilities

- Provide comments and recommendations on the *Risk-based Safety Assessment* document
- Provide consultation on the development of a type certification basis
- Leverage the partner's type certification basis to develop broadly applicable documentation related to the certification process to help other members of industry considering similar commercial operations
- Lead SIO Certification working group meetings
- Coordinate with the FAA through the NASA/FAA research transition team

Partner Responsibilities

- Work toward Type Certification
- Provide data and documentation necessary to support a type certification basis
- Participate in the SIO Certification working group meetings and provide updates on progress toward type certification

Detect and Avoid (DAA)

NASA Responsibilities

- Provide consultation on DAA algorithms, alerting, guidance, displays, and sensors
- Advise on the DAA MOPS requirements and test cases
- Provide existing DAA test cases from previous research activities and consultation on any additional DAA test cases created by the industry partners
- Review and comment on the partner's DAA system implementation, airworthiness, and certification plan
- Lead SIO DAA working group meetings
- Providing access to the NASA DAA algorithms
- Provide results from NASA research activities

Partner Responsibilities

- Develop or provide a DAA system that has a pathway toward certification
- Support RTCA SC-228 Phase 2 MOPS development (if applicable)
- Perform any technology development and testing required to ensure that the DAA system is airworthy

Command and Control (C2)

NASA Responsibilities

- Provide information from subject matter experts regarding the development, verification, and validation of CNPC radios that supported the creation of the RTCA SC-228 C2 standards (DO-362 UAS Terrestrial MOPS)
- Advise on the C2 MOPS requirements and test cases
- Review and comment on the proposer's C2 system development, implementation, certification, and demonstration plan
- Provide consultation on the development of C2 test cases
- Provide consultation on data-link security requirements
- Lead SIO C2 working group meetings
- If required, NASA will provide consultation on spectrum outside the scope of RTCA SC-228 Terrestrial MOPS including satellite communication, Long-Term Evolution (LTE), mesh networks, and other forms of C2
- When available, NASA will share results of an Urban Air Mobility study

Partner Responsibilities

- Develop or provide a C2 system that has a pathway toward certification
- Partner(s) leveraging Terrestrial CNPC or Ka/Ku-Band Satellite communications systems should support the development of the RTCA SC-228 Phase 2 MOPS
- Identify all proposed radio requirements for the UAS
- Develop and implement security protocols
- Perform any technology development and testing required to ensure that the C2 system is airworthy

UAS Technology Integration

NASA Responsibilities

- NASA will comment and provide recommendations on the UAS technologies described in the *System Design Document*
    - Note that NASA may not have the expertise on the SIO team to contribute subject matter expertise for all UAS technologies

Partner Responsibilities

- Provide a UAS capable of demonstrating integrated DAA and C2 technologies, and other technologies required for the commercial mission
- Provide a GCS with a path toward certification as part of their UAS
- Perform any technology development and testing required to ensure that UAS systems are airworthy

RTCA INVOLVEMENT

RTCA Involvement

- NASA's UAS-NAS Project has been involved in the following RTCA Committees
  - RTCA SC-228 Working Group 2 (C2 MOPS)
  - RTCA SC-228 Working Group 1 (DAA MOPS)
  - RTCA SC-147 Working Group 6 (ACAS Xu MOPS)

- If DAA or C2 solutions are based on these MOPS, Partners are strongly encouraged to get involved
  - Visit rtca.org and purchase documents
    - Note: NASA cannot legally provide these documents
  - Join committees that are currently of developing MOPS
    - Listen and contribute as appropriate
  - Work with NASA to bring relevant data and topics to the committee's attention
    - Co-author white papers if appropriate/applicable

UAS-NAS Project Experience

DETECT AND AVOID (DAA)

Operational Foci

Phase 1:

- Aircraft transitioning to and from Class A or special use airspace, traversing Class D and E, and Class G airspace
- Larger UAS capable of carrying an on-board DAA sensor sufficient to meet the performance standards outlined
- Initial users: DoD, DHS, NASA, public agencies

Phase 2:

- SC 228 Phase 2 MOPS
- Terminal Operations
- Alternative, low C-SWaP Sensors
- New Well Clear Definition
- Airspace down to UTM
- Users: Police, Fire, BLM, Forestry, Public Utilities, Fisheries, Agriculture

- MOPS
  - RTCA DO-365 Minimum Operational Performance Standards (MOPS) for Detect and Avoid (DAA) Systems
  - RTCA DO-366 Minimum Operational Performance Standards (MOPS) for Air-to Air Radar Detect and Avoid (DAA) Systems

- Technical Standard Orders
  - TSO-C211, Detect and Avoid
  - TSO-C212, ATAR for Traffic Surveillance

- NASA DAA Team Contributions
  - Well clear definition
  - Alerting
  - Guidance
  - Displays
  - Reference algorithm
  - Significant modeling and simulation

- Well Clear
  - Terminal area
  - Non-cooperative A/C

- Low SWaP Sensor

- Sensor uncertainty mitigation algorithm

- Guidance, displays, alerting updates for terminal area and non-cooperative A/C

- ACAS-Xu/DAA interop logic

- Well Clear Recovery logic/display

- Pilot response timeline
  - Derived RADAR requirements (for new sensors)

DAA: RTCA Participation

- Summary of NASA RTCA participation
  - Ongoing group participation in SC-228 and SC-147
  - Co-lead subgroups in SC-228
  - Elicit community feedback on our simulation designs and present research findings
  - For Phase 1 MOPS, wrote requirements for guidance, display, and parallel test procedures sections
  - For Phase 2 MOPS, are updating requirements for the same sections
- How we can get the partners involved
  - We can act as an information conduit and can present relevant data
  - We can provide contact information so partners may attend meetings (optional)
  - Co-author white papers if appropriate/applicable
- How partners can get access to RTCA DAA documents
  - rtca.org
    - Visit online store
    - At cost for non-members, reduced price for members

DAA Support

CAN Provide	CANNOT Provide
Consultation of DAA system compliance	Fully compliant DAA system
General consultation of DAA algorithms and DAIDALUS code (through GitHub)	Specific tech support of ACAS-Xu or DAIDALUS
Facilitate discussing with AFRL about Vigilant Spirit	Vigilant Spirit
General consultation of alerting, guidance, and display	Integrated algorithm & support algorithm
Results of modeling and sim for SC-228 or planned – NASA "potential" mods to support	Specific Modeling/Sim

DAA questions for PAE ISR

- ACAS-Xu will provide resolution commands to the autopilot
  - What is the role of the pilot?

- Surveillance range for radar is up to 3 km
  - Xu requirements are currently in development. Looking at a smaller well clear definition for Low SWaP with look ahead times being tested closer to 3.5 nm. This surveillance range is a lot less than that.

- Any updates on their transponder testing started in July? Is there a backup?
  - What are the relative closing velocities expected of the vehicle?
  - What is the minimum time to maneuver for intruders?

- How do you plan to ensure radar coverage with the radars located in the wing pods? Will there be a separate radar in each pod?
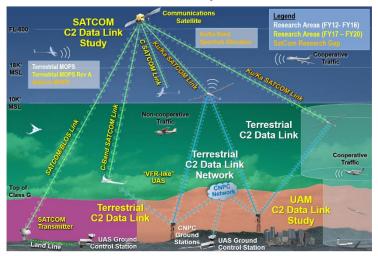
UAS-NAS Project Experience

COMMAND AND CONTROL (C2)
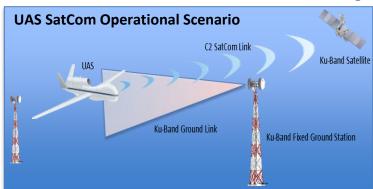
UAS-NAS Command & Control (C2) Subproject

C2 Terrestrial Radio System Standards

- Development of CNPC radios and flight tests that support the development and validation of C2 Terrestrial MOPS, DO-362 Rev A

C2 Urban Air Mobility Study

- Study of UAS communications in the urban operational airspace and communications environment

C2 Ku Terrestrial/SatCom Interference Testing

- Ku-Band flight testing of interference between fixed ground stations and satellite communication to support the FAA Spectrum Office at the World Radio Conference for UAS authorization in the Ku/Ka Satellite spectrum.
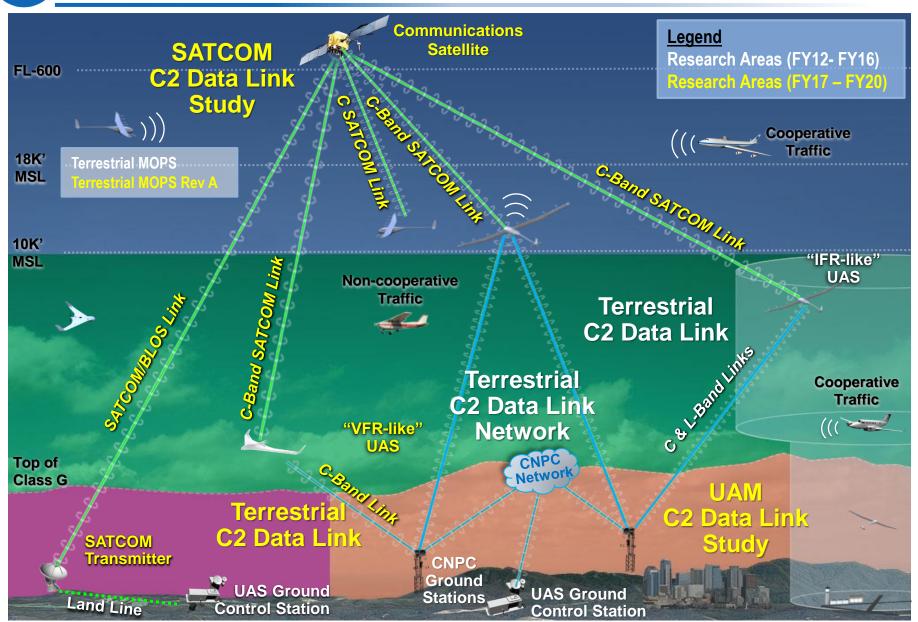
C2 C-Band SatCom Study

- Study the feasibility of an operational satellite-based CNPC system in the approved C-Band spectrum

Phase 1 Flight Accomplishments

UAS Integration in the NAS

Ohio

Colorado

California

Iowa

CNPC Flight Testing Accomplishments (2012-2016)

- 5 generations of prototype Control and Non-Payload Communications (CNPC) radios were used to validate Minimum Operational Performance Standards (MOPS)
  - This spiral development effort was a shared resource cooperative agreement between NASA and Rockwell Collins
- Radios operated in allocated UAS radio frequency spectrum
  - 960 – 977 MHz (L band) & 5030 – 5091 MHz (C band)
  - Performance of both ground and flight radios were characterized
- Testing included hand-off, coverage limits, signal loss and recovery in mountainous, desert, hilly, and over urban and water environments

CNPC Flight Testing Statistics (2012-2016)

- Over 65 mission flights flown
- Over 200hrs of flight data collection
- Over 12,000 miles traveled by the ground station tower trailer
- Operations out of 12 locations

GRC
T-34C

GRC
S-3B Viking

DO-362, C2 Terrestrial MOPS

Gen-5 CNPC Validation Flight Testing (2016)

NASA partnered with Rockwell Collins through a shared resource cooperative agreement to demonstrate and support the development of a Unmanned Aircraft Control and Non-Payload Communications (CNPC) System in both L & C spectrum bands.

- Validation flight testing of the Gen-5 radio was performed in hilly terrain and over-water environments.
- Two flight tests were conducted for each of the environments, at ranges up to 100nmi from the ground station, and at altitudes from 1,000ft AGL up to 17,500ft MSL.

Flight Tracks

CNPC Aircraft Installation GRC T-34C

Spiral	Features
Gen-1	L-Band only, Single Aircraft, Single Ground Station
Gen-2	Added C-Band, Single Aircraft, Multiple Ground Stations Switchovers between ground stations
Gen-3	Multiple Aircraft, Multiple Ground Stations
Gen-4	Update of data rates to perform testing for preliminary C2 MOPS
Gen-5	Updates to radio to align with preliminary C2 MOPS for C2 MOPS V&V

CNPC Aircraft Installation GRC S-3B

Transportable Station Over-Water Sandusky, OH

GS-2 Hilly Terrain Albany, OH

CNPC Gen-5 radios (L & C-Band)

Terrestrial C2 Radio Evaluation System Development

- **Research Objective:**
  - Develop a Terrestrial C2 data link radio system and transfer technology and research data for the development and validation of standards for Terrestrial C2 data link

Terrestrial Challenge

Phase 1 C2 Radio

Phase 2 C2 Radio

- **Status:**
  - Established Cooperative Agreement for C2 Terrestrial Extension radio January 2017
  - Version 6 Preliminary Design Review (PDR) completed July 2017
  - Version 6 Critical Design Review (CDR) completed October 2017
  - Version 6 Flight Test started July 2018
- **Next Steps:**
  - Terrestrial-Based Version 6 Flight Test to be completed October 2018
  - Terrestrial-Based Version 7 Flight Test to be completed July 2019
  - Terrestrial-Based UAS Command & Control Final Report to be completed July 2020

RTCA DO-362 Radio

RF Characteristics

General

Frequency Band -	5030 – 5091 MHz (C-Band)

Frequency Accuracy -   0.2 ppm

Frame Structure -   50 mS TDD structure
Uplink 23 ms, with 1.3 ms Guard Time (24.3 ms)
Downlink 23 ms, with 2.7 ms Guard Time (25.7 ms)
TDD structure synced to UTC clock
$\pm$ 0.00 1mS Timing Accuracy

Transmission Structure -   *Bits/Symbol = 1*
Ramp Up (4 symbols)
Acquisition (32-Bit word)
Preamble (64 or 96 bits, dependent on Data Class)
Data Segments (segmented into 512-bit blocks)
Midamble (32-bit words between data segments)
Postamble (32-bit word)
Ramp Down (4 or 4.5 symbols, dependent on Data Class)

Data Message-   32-bit CRC is calculated and appended to each Data Message
Forward Error Correction (FEC)
   Turbo coding with Code Rate of ~0.62
   Rate 1/3 Turbo Encoder used with Puncturing to maintain code rate
32xM S-Random Interleaver
Pseudorandom Overlay

RTCA DO-362 Radio

Transmitter (Airborne and Ground)

Transmit Power -   C Band (low-power mode): 100 mW
                                 C Band (high-power mode): 10 W

Load VSWR Capability -   VSWR of 2.0:1 or better

Power Spectral Density -   TBD

Transmitter Bandwidth -

Data Class	Channel Width (kHz)
Data Class 1	30
Data Class 2	60
Data Class 3	90
Data Class 4[1]	120

Signal Modulation -

- GMSK with a modulation index of 0.5, Bandwidth-Time product of 0.2
- Modulation bit stream is pre-coded
- Modulation Distortion Less than 5° rms or 20° peak
- Mean frequency error across burst < 0.05 ppm

Modulation Rates -

Data Class	Symbol Rate (ks/s)	Data Rate (kbps)
Data Class 1	34.5	34.5
Data Class 2	69.0	69.0
Data Class 3	103.5	103.5
Data Class 4[1]	138	138.0

[1] Data Class 4 is not required on the Ground Radio Transmitter
[1] Data Class 4 is not required on the Airborne Radio Receiver.

RTCA DO-362 Radio

Receiver (Airborne and Ground)

Adjacent-Channel Rejection -   TBD

Spurious-Response Rejection -   TBD

Receiver Sensitivity -

Mode	L Band Receiver Sensitivity (dBm)	C Band Receiver Sensitivity (dBm)
Data Class 1	-121.0	-118.0
Data Class 2	-118.0	-115.0
Data Class 3	-117.0	-114.0
Data Class 4[1]	-116.0	-113.0

Maximum Receive Strength –   100% performance for a maximum input signal of -10 dBm
Receiver Protection -   Maximum input power before damage +20 dBm

Frequency Capture Range -
Designed for Doppler Shift of ±15 kHz

Center Frequency (MHz)	Maximum Frequency Capture Range (±Hz)
968	15193.60
1000	15200.00
5060	16012.00

[1] Data Class 4 is not required on the Ground Radio Transmitter
[1] Data Class 4 is not required on the Airborne Radio Receiver.

UAS-NAS Project Experience

NO CHASE COA

No Chase COA Flight Demonstration

Need/Goal:

- Less restrictive NAS access for UAS (file and fly)
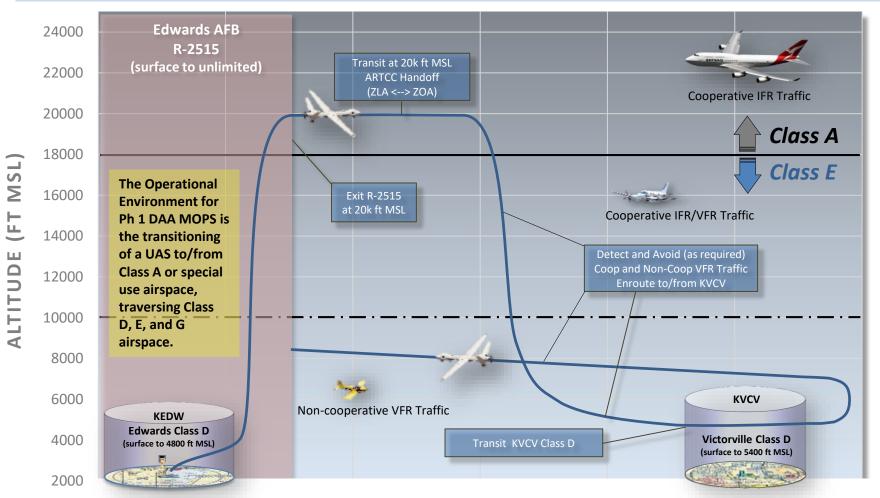
Objectives:

- Demonstrate UA transitioning to/from Class A or SUA through Class E and Class D employing the Phase 1 DAA and Air-to-Air Radar MOPS Systems as alternate means of compliance for 14 CFR 91.111a and 14 CFR 91.113b to "see and avoid/remain well clear" of other traffic during an operationally representative mission

- Obtain FAA COA permitting UAS flight demonstration in the NAS without the requirement for a safety chase aircraft to provide see and avoid functionality

- Engage the FAA certification, safety, and operational approval organizations and in the process, inform policy development and the processing of similar COAs to enable less restrictive UAS access to the NAS

No Chase Aircraft COA Flight Demonstration

Objective: Execute a flight demonstration of a UAS transitioning to/from Class A or SUA to Class E and Class D employing the Phase 1 Detect and Avoid and Air-to-Air Radar MOPS Systems as alternate means of compliance to 14 CFR §91.111(a) and 14 CFR §91.113(b) "see and avoid/remain well clear" regulations

ALTITUDE (FT MSL)

Edwards AFB
R-2515
(surface to unlimited)

Transit at 20k ft MSL
ARTCC Handoff
(ZLA <--> ZOA)

Cooperative IFR Traffic

Class A

Class E

The Operational Environment for Ph 1 DAA MOPS is the transitioning of a UAS to/from Class A or special use airspace, traversing Class D, E, and G airspace.

Exit R-2515
at 20k ft MSL

Cooperative IFR/VFR Traffic

Detect and Avoid (as required)
Coop and Non-Coop VFR Traffic
Enroute to/from KVCV

Non-cooperative VFR Traffic

KVCV

KEDW
Edwards Class D
(surface to 4800 ft MSL)

Transit KVCV Class D

Victorville Class D
(surface to 5400 ft MSL)

Armstrong Flight Research Center Note: C2 (Terrestrial) Datalink MOPS compliant system was not used during this demo

Mission Summary

- No Chase Flight Demo successfully completed

- DAA Systems worked as expected
  - Extended hybrid surveillance on ADS-B equipped aircraft to provide better traffic surveillance with minimal RF impact
  - Sensor fusion provided improved track stability and accuracy
  - ATAR-only track on VFR non-cooperative traffic with an intermittent transponder
  - DAA Alerting and Guidance provided the PIC with excellent situational awareness

- First ever "Traffic Detected" interchange with ATC

- Some Ku downlink dropouts
  - Short durations, likely due to co-channel interference, did not result in loss of situational awareness
  - Highlighted need for DO-362 compliant CNPC datalink

- **FAA Comments:** "Overall, it was a successful event from the ATC and UAS advancement perspectives. In nominal state and following normal ATC/PIC protocols, this was no different than a manned flight under the same conditions."

NCC Lessons Learned/Re-Learned

- There is more to obtaining an operational approval to fly in the NAS than just obtaining a COA approved

- Frequency Spectrum Approval and Equipment Certification
  - Issues:
    - The Project and the AFRC Radio Frequency Spectrum Management Office (RFSMO) did not have a good understanding of the Frequency Spectrum allocation/assignment/approval process for operations outside of SUA when developmental/experimental equipment interfaces with the operational NAS
    - Due to the majority of the DAA and ATAR systems being classified as developmental/experimental, NASA's strategy/safety case development for the NCC flight demos was founded upon demonstrating that the systems to be employed met the "intent" of the Phase 1 MOPS/TSOs. Performance standards gaps would be identified, risks assessed, and mitigations developed.
    - This plan and its implications for obtaining frequency spectrum approval were not fully understood by the NCC Team. NAS operations required NTIA or FCC certified transmitters
    - Although the COA was approved on March 30, 2018, addressing the frequency spectrum issues resulted in delays that pushed the flights into May/June

NCC Lessons Learned/Re-Learned

- Recommendations:
  - Involve the FAA Frequency Spectrum Office early in formulation and ensure inclusion in the SRM process so that all frequency spectrum requirements are understood and accounted for in project planning and coordination
  - Involve the RFSMO early in the Project to initiate National Telecommunications and Information Administration (NTIA) certification process (Federal Agency) or FCC licensing (non-Federal Agency). These processes have long timelines.
  - When hardware/software certifications are not achievable in project timeline, must coordinate project intentions with the FAA early in the COA application and SRM process
  - Vet performance standards gaps and mitigations with the FAA and ensure clear understanding of system limitations
  - The Special Temporary Authorization (STA) process was a work-around that sufficed for this COA, but is not recommended

- Inform SIO flight demonstration planning efforts

UAS-NAS Project Experience

CERTIFICATION

An official recognition that a product complies with its requirements

Doesn't the FAA do certification?

Why is NASA working on certification?

- NASA is interested in "enabling an industry"
- Certification is a challenge
- NASA is a research organization
  - ➤ One area of interest is *safety assurance*

An official recognition that a product complies with its requirements
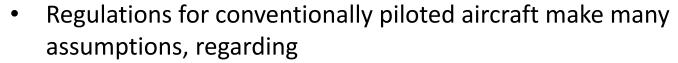
The (primary) aim of aircraft certification (Part 21+) is to provide assurance of the safety by:

- assuring that items perform their *intended (safe) functions* under any foreseeable operating condition

- assuring that *unintended functions* are improbable
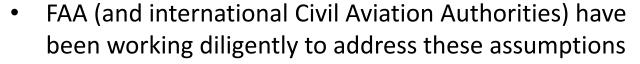
System safety still requires a certified operator (Part 61?) and compliant operations (Part 91+)
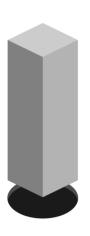
Why is UAS Certification Hard?

- Regulations for conventionally piloted aircraft make many assumptions, regarding
  - Operational models
  - Control models
  - Hazards
  - Technologies
  - Failure modes

- FAA (and international Civil Aviation Authorities) have been working diligently to address these assumptions
  - Part 23 rewrite

- Lack of real-world certification examples

➢ NASA's UAS-NAS SIO

Approach

Each partner

Activity	Output
Describe operation and aircraft	Conops
Hazard Assessment (id & classification)	Risk-based Safety Assessment
Select hazards mitigated by aircraft cert	Type Cert Basis
Develop hazard mitigations	Means of Compliance
Methods to collect evidence of compliance	Test reports, analysis, etc.

- NASA collects information above for each partner
- Develops common hazards and mitigations
  - "Lessons Learned"
- Identifies gaps in safety assurance
- Special topics (resources permitting)
  - Automation / Autonomy
    - V&V of advanced data-driven techniques like machine learning.
  - One operator multiple vehicles
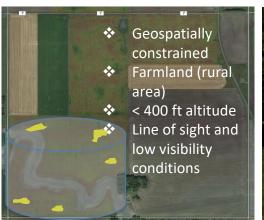
Topics for Partners to Consider

- NASA Airworthiness for demonstration and Civil Airworthiness Certification
- Airworthiness Certification can be thought of as three parts: designed to be airworthy, manufactured to be airworthy, and maintained to be airworthy.
- Don't look to NASA to provide certification expertise. Internal and/or consultants in civil certification are needed.
- Certification relies on repeatable engineering practice
  - Is the evidence produced in a consistent, repeatable manner?
  - Are design and certification artifacts maintained throughout the lifecycle?
- Appreciate that common ideas in UAS do not have a heritage in FAA certification
  - Detect and Avoid
  - Ground control stations
- FAA is concerned about overall safety (not just airworthiness). Consider an operations manual and a maintenance manual
- Be careful about operational limitations to avoid certification requirements
- How to use demonstration activity as a means to prepare for certification
  - Flight test plan
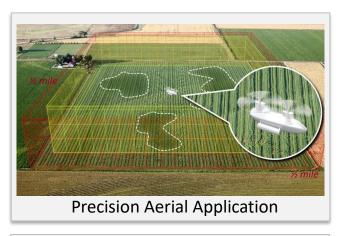
- NASA conducted an evaluation of certification requirements for a midrange UAS
- Developed and evaluated concept of operations for low risk UAS operations
  - Agricultural
  - Rural cargo delivery.
- Identified design requirements from an analysis of hazards

Precision Aerial Application

Cargo Delivery in Uninhabited Corridors

❖ Geospatially constrained
❖ Farmland (rural area)
❖ < 400 ft altitude
❖ Line of sight and low visibility conditions

Publications

- K. J. Hayhurst, J. M. Maddalon, N. A. Neogi, H. A. Verstynen. *Design Requirements for Unmanned Rotorcraft used in Low-Risk Concepts of Operation*, NASA Technical Memorandum 219345. October 2016.
- Kelly J. Hayhurst, Jeffrey M. Maddalon, Natasha A. Neogi, Harry A. Verstynen. *Safety and Certification Considerations for Expanding the Use of UAS in Precision Agriculture*. 13th International Conference on Precision Agriculture, St. Louis, MO. July 31-Aug 4, 2016.
- Neogi, N. A., Hayhurst, K. J., Maddalon, J. M., and Verstynen, H. A. *"Some impacts of risk-centric certification requirements for UAS."* In Unmanned Aircraft Systems (ICUAS), 2016 International Conference on (pp. 1003-1012). IEEE. June 2016.
- J.M. Maddalon, K.J. Hayhurst, N.A. Neogi, H.A. Verstynen, and R.A. Clothier. *Expanding the Envelope of UAS Certification: What it Takes to Type Certify a UAS for Precision Agricultural Spraying*. XPONENTIAL 2016. New Orleans, La. May 4, 2016.
- K. J. Hayhurst, J. M. Maddalon, N. A. Neogi, H. A. Verstynen, Barry Buelow, and G. Frank McCormick. *Mock Certification Basis for an Unmanned Rotorcraft for Precision Agricultural Spraying*, NASA Technical Memorandum 218979. November 2015.
- K. J. Hayhurst, J. M. Maddalon, N. A. Neogi and H. A. Verstynen, *A case study for assured containment*, Unmanned Aircraft Systems (ICUAS), 2015 International Conference on, Denver, CO, 2015, pp. 260-269.
- Kelly J. Hayhurst, Jeffrey M. Maddalon, A. Terry Morris, Natasha Neogi, Harry A. Verstynen, *A Review of Current and Prospective Factors for Classification of Civil Unmanned Aircraft System*. NASA Technical Memorandum 218511, August 2014.
- J.M. Maddalon, K.J. Hayhurst, A.T. Morris, and H.A. Verstynen, *Considerations of Unmanned Aircraft Classification for Civil Airworthiness Standards*. Presented at AIAA Infotech Conference, August 19-22, 2013, Boston, Massachusetts.
- Jeffrey M. Maddalon, Kelly J. Hayhurst, Daniel M. Koppen, Jason M. Upchurch, A. Terry Morris; and Harry A. Verstynen. *Perspectives on Unmanned Aircraft Classification for Civil Airworthiness Standards*. NASA Technical Memorandum 217969. February 2013.
- Kelly J. Hayhurst, Jeffrey M. Maddalon, Paul S. Miner, George N. Szatkowski, Michael L. Ulrey, Michael P. DeWalt, Cary R. Spitzer. *Preliminary Considerations for Classifying hazards of Unmanned Aircraft Systems.* NASA Technical Memorandum (TM-2007-214539), February 2007.
- Kelly J. Hayhurst, Jeffrey Maddalon, Paul Miner, Michael DeWalt, Frank McCormick. *Unmanned Aircraft Hazards and Their Implications for Regulation*. 25th Digital Avionics Systems Conference (DASC). 2006.
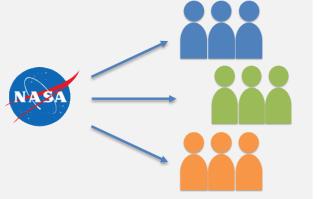
WORKING GROUP STRUCTURE AND COMMUNICATIONS
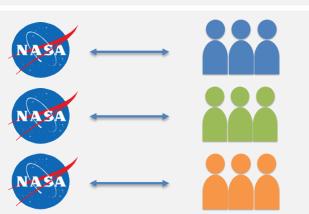
Types of Communications

NASA to All Partners

- General SIO scope, schedule, NASA resource allocation, etc.
- Lessons learned from previous research activities
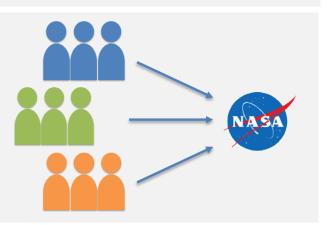- Broadly applicable information on airworthiness, certification, DAA, and C2

Between NASA Individual Partners

- Exchange of UAS specific technical information
- Recommendations
- Certification discussions
- Anything else that is proprietary

All Partners to NASA

- Limited communications in order to protect proprietary information
- General information
- Publicly available information
- Input to standards groups (e,g., RTCA)

Working Group Meetings

Purpose of working group meetings

- – Support technical information exchange
- – Share NASA research results with partners
- – Coordination of operational approval for the FY2020 demonstration
- – Support work toward type certification

Proposed working group meetings

- – Detect and Avoid
- – Command and Control
- – Airworthiness and Certification
- – Management

Proposed meeting frequency

- – Bi-weekly working group meetings
- – Special topic meetings can be set up as needed

Coordination with the FAA via the Research Transition Team

- – With approval of the industry partners, NASA may want to provide the FAA with a select documents

Semi-Annual Meeting

- Semi-annual meeting purpose
    - Conduct in depth review of progress, project risks, and project outcomes
    - Facilitate in-person interaction between the NASA and Partner teams

- Schedule and location will be coordinated with Partner as SIO progresses
    - Locations and schedule should be determined at least three months prior to the semi-annual meeting to maximize participation

NASA RESOURCE CONSTRAINTS

NASA Resource Constraints

> **NASA is committed to using the personnel allocated to SIO to help the industry partners advance toward commercialization and to provide guidelines and lessons learned to the entire UAS community**

NASA in-kind support

- FY2019
  - 2.0 work year equivalent for DAA consultation and support
  - 1.5 work year equivalent for C2 consultation and support
  - 2.0 work year equivalent for airworthiness consultation and support
  - 1.5 work year equivalent for Live Virtual Constructive (LVC) test environment support
  - 2.5 work year equivalent for certification consultation and support, and for generating broadly applicable certification documentation
  - 1.0 work year equivalent for management of the Cooperative Agreements
- FY2019
  - 2.0 work year equivalent for DAA consultation and support
  - 1.5 work year equivalent for C2 consultation and support
  - 2.0 work year equivalent for airworthiness consultation and support
  - 1.5 work year equivalent for Live Virtual Constructive (LVC) test environment support
  - 2.5 work year equivalent for certification consultation and support, and for generating broadly applicable certification documentation
  - 1.0 work year equivalent for management of the Cooperative Agreements

- Equivalent to approximately 10.5 people per year, supporting 3 industry partners (3.5 people per partner)

Balancing Resources Between Multiple Partners

- NASA's personnel will support multiple partners

- NASA will strive to provide an equitable amount of support to all partners

- Partners should communicate the priority of actions requested from NASA (e.g., deadlines, schedule, etc.)

- Any concerns about inadequate support from NASA should be brought to the attention to UAS-NAS project management as soon as possible

Balancing Schedule Between Multiple Partners

- FY2020 Demonstration Scheduling
  - NASA will work with the SIO partners to determine an acceptable demonstration schedule

- Documentation review priority
  - Documentation will be reviewed in the order it is received unless there are special circumstances that warrant expedited review
  - Providing documentation prior to the deadlines will facilitate faster review by spreading out the dates when they are received

- SIO action items
  - Action items are expected to come out of the working group meetings
  - Each action will be assigned a due date and priority level
    - **High priority:** Required for the success of the FY2020 demonstration
    - **Medium priority:** Substantial benefit to partner's Type Certification efforts, development of standards, or reduces risk associated with the FY2020 demonstration
    - **Low priority:** Beneficial, but does not meet the criteria of high or medium priority
  - Due date and priority will be balanced to determine most pertinent actions

PUBLIC RELATIONS

Public Relations

- Public Relations is an important component of SIO
  - Generate public awareness of SIO
  - Increase social acceptance of UAS

- Public relations partnership
  - NASA/Partner must get approval before using each others logos
  - NASA/Partner should ensure common awareness of public presentations related to SIO
  - NASA/Partner should jointly approve any applicable media releases related to SIO

- NASA will work with the Partner to put together a communications plan
  - Describe project background
  - Key messages
  - Key contacts
  - Media events
  - Public relations products that NASA and the Partner would like to release

DATA MANAGEMENT AND INTELLECTUAL PROPERTY PROTECTION

Protection of Proprietary and Restricted Data

> **NASA is committed to protecting out partners' intellectual property and adhering to any applicable data restrictions, while providing useful non-proprietary information to the broad UAS community**

- Protection of proprietary information begins with clear communication of data and documentation that are proprietary/restricted
  - When providing documentation, NASA is asking for both a unrestricted and a restricted versions of documents to facilitate clear communication
  - Partners should clearly mark any information that is restricted with appropriate markings (e.g., proprietary, ITAR)
  - **Partners should not provide NASA with classified data**
  - NASA will integrate data rights into a Project level data management plan
  - NASA will provide any papers/documents produced as part of SIO for partners to review
    - For documents that include information from multiple Partners, NASA will first allow each Partner to review portions applicable to their concept/data and then allow all partners to review a final draft of the document

Data Lifecycle

Data Storage and Sharing During Project

- NASA is looking into setting up SharePoint sites for document storage and access
  - We are also willing examine the feasibility of using systems hosted by our Partners
- NASA's large file transfer system can be used to securely transfer documents

Data Archiving After Project Completion

- All unrestricted documents will be retained in a project archive and on NASA computers
- Unrestricted documents, or portions unrestricted documents, may be publicly released (NASA will work with Partners)
- Proprietary documents will be removed from NASA computers within a reasonable period of time after project completion unless NASA regulations/policy require them to be kept
  - Any documents required for NASA airworthiness approval will be retained by the Armstrong Chief Engineer's office
  - Current processes will be used to protect restricted information

FAA PARTICIPATION

AIRWORTHINESS AND OPERATIONAL APPROVAL

- Insure a clear understanding by both NASA and the SIO Partner as to:
  - Feed back to the Partners what NASA thinks they are planning to do to see if we got it right or it needs changing.
  - The airworthiness process to be implemented.
  - NASA involvement or lack thereof.
    - What attendance at what key events?
    - Clear expectations as to what NASA will or will not do under as part of this partnership.
  - Documentation required by Partner for the demo (not necessarily the SIO deliverables though it may be same or similar).
  - Documentation needed from NASA by Partner to carry out their plans.
  - Agree on the schedule (no doubt it will change).
  - POCs/key players along with roles and responsibilities for both NASA and Partner regarding airworthiness.
  - NASA Definitions for key terms such as "Airworthiness" --- need a short list of key terms.

- Assumptions
  - Permissions from AMD

- Possible Issues
  - Possible resource constraints
  - Possible schedule constraints – reiterate important drop-dead dates

Governing Policy and Practices

- Generally, all activities conducted in collaboration with NASA (where NASA resources are expended) need to be done in accordance with NPR 7900.3D.
  - NASA Armstrong's airworthiness process defined in AFG-7900.3-001, AFOP-7900.3-022, and AFOP-7900.3-023 were developed in response to NPR 7900.3D and are used to carry out the Agency directive.
  - The Armstrong process is designed to be tailorable depending on the risk posture of each of the planned SIO Demos.
- The GA & PAE-ISR SIO activities will be viewed by NASA as "data buys" and therefore the NPR 7900.3D may be relaxed or determined to not be applicable.
  - NASA HQ Aircraft Management Directorate (AMD) decision with Armstrong inputs.
- PAE-ISR is expected to work with the PPUTRC/PUR using the Public Aircraft airworthiness process authorized by the FAA to acquire the flight certificate.
  - Need to determine if an existing COA (PUR's) would be used or if a new one will be applied for by PAE-ISR.
- Since all SIO activities are planned to be flown in the NAS under COAs, the FAA will also have policy directives that may apply.

- SIO Demo:
  - Low altitude flight series over a low population density area (remote) located in the Pendleton UAS Test Site.
  - Approvals required:
    - Airworthiness certificate form Pendleton UAS Range
    - COA with the FAA
    - LOAs with local ATCs

PAE-ISR Program & Airworthiness (PPUTRC) Schedules Draft